Plug and Play Integration through Space Object Standardization

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ABSTRACT

Plug and play is an industry standard promoted by Intel and Microsoft, and others that allows users to add and remove various input and output devices without making specific customizations to their systems. The idea behind this concept is that using standard products eases integration of components and promotes capabilities of conforming products. The concept works because vendors comply with a standard specification. This paper reports the development of a reference architecture for the mission control domain, which is leveraging off this revolutionary concept. Standards are being developed at the application layer, which enable "plug and play" of mission software products. A Mission Control, reference architecture has been defined. For each sub-domain, the interfaces are modeled in Interface Definition Language (IDL). A subset of the IDL has been developed within both commercial off-the-shelf (COTS) and government (GOTS) products. Selected vendors have agreed to modify their products to be compatible with the defined IDL. The plug and play integration of these different products has been validated in a demonstration testbed.

Keywords: Plug and play, reuse, standard, CORBA vertical domain, space command and control.

INTRODUCTION

The Space Object Technology Group (SOTG) is a consortium, which includes the National Aeronautics and Space Administration (NASA), at Goddard Space Flight Center (GSFC), the National Reconnaissance Office (NRO), Computer Sciences Corporation (CSC), Raytheon Corporation, Altair Aerospace Corporation and TASC. The SOTG was formed on September 2, 1998. The goals of the SOTG are to reduce the risk and cost of mission control systems implementation through the development and use of a standard plug and play architecture and to promote interoperability and reusability between applications. Given the absence of any standard at the application layer this group is developing and validating a standard with the aim of producing a specification that enables true plug and play integration. The SOTG vision of the future is mission control systems that are manufacture and platform independent; systems are built from distributed COTS and GOTS products. These products are built with modern object oriented interfaces and communications standards, allowing multiple choices in mission control applications for government agencies and the aerospace community.

ENVIRONMENTAL FACTORS

The Mission Control environment can be characterized as highly customized to mission specific requirements. Applications such as mission planning, spacecraft monitoring, commanding, flight dynamics and data acquisition are unique for each mission. They are reengineered each and every time requiring extensive development efforts. Testing of mission capabilities is also unique and costly. Unique spacecraft hardware drives the unique spacecraft control applications. Mission Control system requirements are typically defined late in the mission lifecycle after hardware has been well defined. All of these factors contribute to increased mission costs and multi-year implementations.

It is far too limiting to force a single spacecraft control architecture on multiple projects and poses the risk of not meeting mission objectives. The software reuse concept is appealing, but has not been practical until recent technological advances were made and standard interfaces defined. The SOTG has the charter of defining standards for space related objects, thus promoting interoperability among objects produced by multiple vendors. There are numerous advantages in accomplishing such a goal. First, it reduces mission risk through establishing common interfaces. Secondly, it reduces cost through shortened development life cycle and minimized mission customization. Finally, it promotes vendor competition, increasing capabilities available for use throughout industry.

SOTG PRODUCTS

Initially, the SOTG focussed on identifying enabling technology, group membership and processes to be used. The enabling technology would provide the network transparency necessary for a plug and play environment. The two leading technologies for this are the Common

Object Request Broker Architecture (CORBA) and COM/DCOM. CORBA was selected because of its ability to support heterogeneous platforms and systems and the fact that it is not proprietary. COM/DCOM applications could still interface with the specified system by following standard CORBA – COM/DCOM interfaces. Object request brokers (ORBs) which follow the CORBA standard would provide the network transparency necessary for a plug and play environment. The use CORBA also meant that the Object Management Group's (OMG's) Interface Definition Language (IDL) would be used to specify the interfaces between the subdomains. Use of CORBA also allowed a vertical domain definition via the Object Management Architecture (OMA) shown in Figure 1. Maximum use was made of the stable CORBA Services in order to reduce the risk and cost, and to increase interoperability and plug and play capabilities.

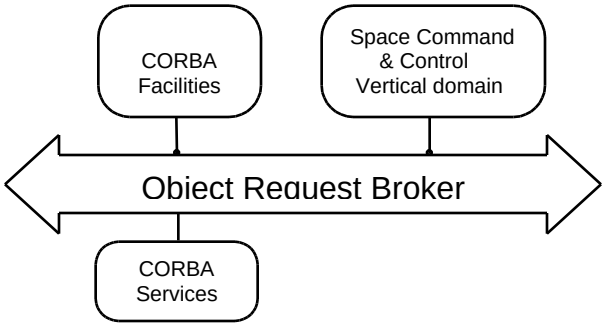

Figure 1. Space Vertical Domain

APPROACH

The SOTG activity was broken into 3 phases:

- Phase 1 Domain Definition and Reference Architecture Definition
- Phase 2 Subdomain Prototype
- Phase 3 Complete subdomain definition and demonstrate

PHASE 1 - DOMAIN AND REFERENCE ARCHITECTURE DEFINITION

The goal of Phase 1 was to define the space command and control domain and the associated reference architecture. A Domain Definition Document and a specification for a Reference Architecture Document were developed. In addition to the documentation, the group selected Phase 2 prototype subdomains.

High level requirements for the domain were specified as follows:

- Space ground neutral - allowing specific implementations to decide where functions are performed
- Neutral on centralization vs. distributed architecture
- All inclusive for the space mission operations domain
- Reference architecture and implementation choose required pieces of domain for specific implementations.

The scope of the domain definition in relation to the end users mission identified seven major criteria: orbit, mission phase, range/ground support, mission constellation, telemetry streams, manned/unmanned missions and operational mode. The domain was to be able to support any orbit (i.e. suborbital, captive earth, interplanetary LaGrange). All mission phases were to be supported (factory test to end of life). Ground support could be either dedicated or shared. The criteria for mission constellation and telemetry stream were to have no architectural limitations. The domain also had to be able to support manual, interactive or lights out operational mode. Put simply the domain was required to be all encompassing for space mission operations and control without placing limitations on the specific implementations.
In order to meet these criteria it was necessary to partition the space command and control domain into subdomains and to allocate functions to each individual subdomain.

The SOTG subdomains definitions are:

- data acquisition
- commanding
- automation
- authorization
- remote processors
- orbit
- attitude
- maneuver
- scheduling
- vehicle modeling

A reference architecture plays a dual role with regard to specific target system architectures. First it generalizes and extracts common functions and configurations. Second, it provides a base for instantiating target systems that more reliably and cost effectively uses that common base.[1] The SOTG reference architecture encompasses those elements that are common and shareable across target space-ground architectures. It includes:

- Requirements and a object-based framework for developing the key domain and support elements of space-ground software systems;
- Key supporting mechanisms that define the common concepts and means of interaction that elements of the architecture use;

- Constraints that define what properties any target must display in order to be judged compliant with the reference architecture; and
- Conformance criteria that govern implementations of the reference architecture and its constituent elements.

The reference architecture document produced in this phase not only included the above but also contained a reference architecture model. The model was expressed as an Object Management Architecture view. Requirements for the services and subdomains specify the interfaces and supporting data that SOTG models are expected to provide.

On November 19, 1998 the SOTG steering committee met and voted on the Phase 1 products. The vote was unanimous in accepting the domain and reference architecture. Phase1 feasibility had been demonstrated.

PHASE 2 – SUBDOMAIN PROTOTYPE

The goal of Phase 2 was to select a subset of the subdomains and define the components, requirements and to specify the interfaces in IDL. Three working groups were formed to examine two subdomains and the SOTG services required by those subdomains. Each working group was led by a different organization. The lead of each working group was selected and the subdomains identified. The two subdomains chosen were data acquisition and automation

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Phase 2 Reference Architecture requirements were:

- Support interoperability among objects comprising its targets
- Not rely on specific implementations
- Support the definition of deterministic operations for all time-critical operations
- Support deployment on a variety of ground and space processors
- Support the addition and modification of new elements with minimal impact to the underlying structure
- Contain larger-grained components, each having a well-defined interface that hides its implementation or its use of lower-level components

Integration

An iterative process was developed for integration of subdomain products and is described below and shown pictorially in Figure 2.

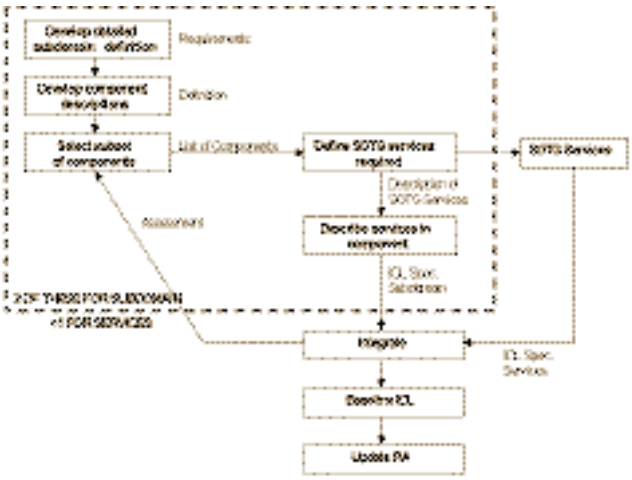

Figure 2. Subdomain Definition Process

The component definition process started with defining detailed requirements for the data acquisition and automation subdomains. Once this was completed the component descriptions for these subdomains were defined. All requirements and component descriptions were Documented in the reference architecture document. Implement of as many components as possible within the subdomain was accomplished. Priority was given to components that interfaced with the other subdomain being implemented and to components that would be used for multiple missions. The working group then defined what SOTG services would be required for that subset of components. These were then given to the SOTG service working group to be used as requirements for the services. The subdomain working group then implemented the IDL for the selected components and integrated this iteration of components was then integrated. Another iteration of this cycle followed for the subdomain components. At the end of the second iteration the SOTG services were also integrated with the IDL from the two subdomains. At the end of the two iterations the IDL was baselined and the SOTG Reference Architecture document was updated.

During this phase two types of commercial products were used by the SOTG working groups. Rational Software's ROSE was used for the development of the IDL. Three different vendors' products were used for ORBs; Visigenic's Visibroker, IONA Technologies: ORBIX and Washington University's TAO. The three ORBs selected were used because they were available at the distributed sites of the SOTG members. Defining the IDL for the data acquisition and automation sub-domains and implementing these in the SOTG testbed was used to validate the concept for the SOTG reference architecture.

All Phase 2 products are available on the Web at http://sotg.gsfc.nasa.gov.

PHASE 3 – COMPLETE SUBDOMAIN SPECIFICATION

Phase 3 involves completion of the remaining subdomain IDLs and development of a demonstration capability using vendor products. Work on Phase 3 is currently in progress and an update of the progress will be given at the conference.

LESSONS LEARNED

One of the first problems encountered by both groups was terminology. Though all team members had been working in the "space command and control" environment for many years it was with different customers. This resulted in confusion. Several times agreement was reached in a group only to find out latter that there was a misunderstanding. Members addressed this problem by creating and agreeing on a glossary of terms. This not entirely solved the problem because there was not much success in coordinating and updating the glossary.

A second issue encountered was trying to get disparate groups to reason collectively about reuse and components. Each group brought their own experience, along with operations concepts and system solution “styles”, to the SOTG, and much time was spent in discovery of the differences. In hindsight there may have been something we could have done more up front in the requirements analysis timeframe. Each group summarizing their architecture drivers and system solutions prior to the requirement generation activity would have made latter activities more efficient.

Working groups composed of mixed organizations, though slow to become fully effective (as mentioned in the above two paragraphs) were critical to the SOTG reaching consensus on the end products. Forming the working groups with limited memberships to develop the products would have been more efficient, but it is doubtful that consensus would have been achieved on the final product.

Another lesson learned was that having team leads participating on all working groups in order to coordinate activities between groups was very successful. There were no “surprises” for any of the groups. All of the working groups adapted to changes as they occurred. This was primarily because of the cross working group membership.

PARALLEL PHASE - INDUSTRY STANDARD

Since its formation the SOTG had the goal of developing a standard for plug and play within the space command and control domain in order to reduce cost and risk. A number of standard setting bodies were examined to see which was the most appropriate for this activity. It was decided that the Object Management Group was the best fit for the goals. Their processes and goals were similar,[2] they were oriented toward CORBA, they already had processes for other vertical domains and they had processes in place to interface with other standard bodies. An initial discussion was held with the OMG to discuss possibility of using their process to set the standard in October of 1998. The discussion indicated that it would be beneficial for both sides to examine the issue more closely. In January a contingent of SOTG members participated in an OMG technical meeting. All members reported back that the OMG processes seemed to be appropriate for developing a Space Command and Control vertical domain. The government members of the SOTG felt that SOTG industry representatives should take the lead in the OMG since it would be an industry standard and not a government standard. At the March OMG technical meeting members of the SOTG gave a presentation to the C4I special interest group on the SOTG activities. After the presentation the SIG took a vote to determine if there was any interest in forming a working group to develop the space command and control vertical domain. The SIG voted unanimously to sponsor the working group. The near-term schedule for the OMG activity consisted of a pre-kickoff presentation in Tokyo in May and the actual kick off meeting for the space command and control working group at the OMG technical meeting in August in San Jose. All of the SOTG work will be used to seed the working group during its processes to adopt standards for the space command and control vertical domain. At this point in time SOTG members are taking the lead in establishing the working group. It is currently envisioned that the working group will follow the processes of issuing Letters of Intent (LOI), Request for Information (RFI), and Request for Proposal (RFP) and proposals to set the standards for the vertical domain. The working group will determine the details of this activity once it is formed. It is currently estimated that it will take approximately one year to establish the standards for the vertical domain and possibly another year before commercial space command and control standard compliant software is available.
One unforeseen benefit that has occurred is that other OMG vertical domains have also requested to participate in the working group, specifically the in the areas of resource scheduling and planning and graphical information systems. Participation by members from these areas would help ensure that non-space related commercial software would be able to seamlessly plug and play with the space command and control domain components. This would further reduce the cost and risk in implementing a system for space command and control.

FUTURE WORK

Post Phase 3 activities will continue within the government led and industry lead areas. The government led activities in this era are by the NRO and by NASA/GSFC. NRO plans to implement the SOTG reference architecture in support of at least one of their missions. GSFC is evaluating missions for use of the reference architecture and is working with the Space Operations Management Office (SOMO) located at Johnson Space Flight Center for incorporation into the NASA wide Operations Contract. The OMG space command and control working group activities represent the industry led activity. Organizations wanting to participate in this represent government contractors, commercial contractors, government and commercial clients, domestic and foreign.

CONCLUSIONS

The SOTG has already successfully prototyped the concept of developing a standard for developing a space command and control system. The work performed by the SOTG also appears to provide the jump-start needed to start the development of an industry standard. Based on organizational interest at both the SOTG and OMG level there appears to be the required critical mass to define a standard that is of benefit to both clients and vendors. True plug and play of subdomains appears to be within reach.

ACKNOWLEDGEMENTS

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